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Year	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	2100																			
Population	1,200,000	1,250,000	1,300,000	1,350,000	1,400,000	1,450,000	1,500,000	1,550,000	1,600,000	1,650,000	1,700,000	1,750,000	1,800,000	1,850,000	1,900,000	1,950,000	2,000,000	2,050,000	2,100,000	2,150,000	2,200,000	2,250,000	2,300,000	2,350,000	2,400,000	2,450,000	2,500,000	2,550,000	2,600,000	2,650,000	2,700,000	2,750,000	2,800,000	2,850,000	2,900,000	2,950,000	3,000,000	3,050,000	3,100,000	3,150,000	3,200,000	3,250,000	3,300,000	3,350,000	3,400,000	3,450,000	3,500,000	3,550,000	3,600,000	3,650,000	3,700,000	3,750,000	3,800,000	3,850,000	3,900,000	3,950,000	4,000,000	4,050,000	4,100,000	4,150,000	4,200,000	4,250,000	4,300,000	4,350,000	4,400,000	4,450,000	4,500,000	4,550,000	4,600,000	4,650,000	4,700,000	4,750,000	4,800,000	4,850,000	4,900,000	4,950,000	5,000,000	5,050,000	5,100,000	5,150,000	5,200,000	5,250,000	5,300,000	5,350,000	5,400,000	5,450,000	5,500,000	5,550,000	5,600,000	5,650,000	5,700,000	5,750,000	5,800,000	5,850,000	5,900,000	5,950,000	6,000,000	6,050,000	6,100,000	6,150,000	6,200,000	6,250,000	6,300,000	6,350,000	6,400,000	6,450,000	6,500,000	6,550,000	6,600,000	6,650,000	6,700,000	6,750,000	6,800,000	6,850,000	6,900,000	6,950,000	7,000,000	7,050,000	7,100,000	7,150,000	7,200,000	7,250,000	7,300,000	7,350,000	7,400,000	7,450,000	7,500,000	7,550,000	7,600,000	7,650,000	7,700,000	7,750,000	7,800,000	7,850,000	7,900,000	7,950,000	8,000,000	8,050,000	8,100,000	8,150,000	8,200,000	8,250,000	8,300,000	8,350,000	8,400,000	8,450,000	8,500,000	8,550,000	8,600,000	8,650,000	8,700,000	8,750,000	8,800,000	8,850,000	8,900,000	8,950,000	9,000,000	9,050,000	9,100,000	9,150,000	9,200,000	9,250,000	9,300,000	9,350,000	9,400,000	9,450,000	9,500,000	9,550,000	9,600,000	9,650,000

a PZT actuator element and PZT sensing element pursuant to an embodiment of the invention.

DESCRIPTION OF THE INVENTION

For purposes of illustration and not limitation, Figure 1 illustrates schematically a low power, light-weight, thin profile piezoelectric fan 10 having a movable member 12 such as a flexible blade, plate or diaphragm fixed at one end 12a by clamp plates 13 on a housing 14 and free at the other end 12b to move up and down in the housing in Figure 1 in a bending vibration mode near or at a fundamental resonance of the movable member 12. The housing 14 includes an inlet aperture 14a for fluid such as air and an outlet aperture 14b through which fluid is ejected; e.g. a cooling air stream is ejected through aperture 14b. Piezoelectric fans are known in the art and described in U.S. Patents 4 780 062; 5 861 703; and 5 921 757 for example, the teachings of which are incorporated herein by reference. The invention is not limited to any particular piezoelectric fan and can practiced with piezoelectric fans of various types, pumps, microjet generating devices described in copending application entitled "THIN PROFILE PIEZOELECTRIC JET DEVICE" of common inventorship herewith (attorney docket number PU62), the teachings of which are incorporated herein by reference, and other piezoelectric devices operable to move a fluid. Piezoelectric fans and pumps are commonly employed to generate a moving air flow for use in cooling portable electronic devices, such as cell phones, laptop computers, personal digital assistance devices and the like.

A first piezoelectric (PZT) actuator element 20 is coupled to (e.g. bonded on) the movable member 12 to drive or actuate the movable member in a bending vibration mode near or at its fundamental resonance to move fluid through the aperture 14b. The PZT element 20 is adhesively bonded on the top side of the movable member 12 and can comprise a conventional ceramic or polymer (e.g. polyvinylidene fluoride (PVDF)) PZT element having two metal (e.g. Ni, Ag, etc.) electrodes 21', 21 on opposite sides connected by lead wires 22 to an electronic microprocessor controller 30. The inner electrode 21' adjacent the movable member 12 is a grounded electrode.

The PZT element 20 is connected to electronic microprocessor controller 30 that provides periodic alternating voltage signals to the PZT element 20 at a frequency to drive the movable member 12 near or at resonance. The periodic alternating voltage signals cause the PZT element 20 to contract and expand periodically to drive the movable member 12 as is well known. The controller 30 can be a conventional phase locked loop type of controller including an electrical power source (drive circuit) S to drive PZT elements at resonance as determined by the particular periodic alternating voltage output signal provided by the source S to the PZT element 20.

Pursuant to an embodiment of the invention, a second piezoelectric (PZT) sensing element 40 is coupled to (e.g. bonded on) the opposite bottom side of the movable member 12, although the elements 20, 40 can be bonded on the same side of movable member 12 or their positions reversed from those shown. The PZT sensing element 40 is used to provide feedback information regarding at least one of fluid viscosity, fluid density, and fluid temperature to controller 30. To this end, the sensing element 40 includes two metal electrodes 41 on opposite sides. The inner electrode 41' adjacent the movable member 12 is a grounded electrode, while the outer electrode 41 is connected by a lead wire 42 to the controller 30. The second PZT element 40 also can be used to drive the movable member 12 in conjunction with the first PZT element 20 in accordance with alternating voltage signals supplied from the controller 30 to both PZT elements 20, 40. Although electrodes 21, 21'; 41, 41' are shown as overlying the entire sides of the elements 20, 40, those skilled in the art will appreciate that the electrode elements can be present as smaller areas or patches of any configuration on the sides of elements 20, 40.

The controller 30 includes a conventional phase locked loop circuit (not shown) to maintain at 90 degrees the phase difference between the signal emerging from the PZT element 40 and the signal input to the actuator PZT element 20. This insures that the controller 30 tracks the natural frequency of the movable member 12 as it changes with changing external conditions such as fluid temperature, viscosity and density. The movable member 12 thereby

can be driven at resonance to achieve near maximum amplitude and fluid moving (e.g. air blowing) efficiency. Such phase locked loop circuits are commercially available.

The PZT sensing element 40 and its lead wire 42 are used to provide to controller 30 feedback information (signals) that can be correlated to changes in viscosity and/or density of the fluid being moved by the movable member 12. For example, for the same input force on movable member 12 from PZT actuator element 20, the damping of vibration of movable member 12 (and thus that of PZT sensing element 40) will depend on the viscosity of the surrounding fluid. This principle is commonly found in the design of vibratory viscometers. The amplitude of the signal at resonance (voltage amplitude signal) provided by PZT sensing element 40 can be calibrated to represent the viscosity of the fluid being moved at a given time. Alternately, or in addition, the bandwidth of the peak of the voltage signal provided by the PZT sensing element 40 can be calibrated to represent the viscosity of the fluid being moved at a given time. The bandwidth can be determined by comparing phase response of the signal just before and just after resonance as controlled by appropriately varying frequency of excitation of the movable member. The greater the damping by the fluid, the slower the phase angle of the voltage signal drops off away from resonance as is well known. The calibration data can be stored in controller memory as gain values (voltage bias values) and accessed by controller logic to make the determination of fluid viscosity at a given time by comparing the signal received from the sensing element 40 at a given time with the stored calibration data.

Furthermore, if the density of the fluid being moved changes the natural frequency of vibration of the movable member 12 (and thus that of PZT sensing element 40) changes due to the changed "added mass effect" attributable to the fluid density change. The controller 30 can track and determine the change in natural frequency of vibration (alternating voltage frequency signal) of the PZT sensing element 40 such that the change of the natural frequency can be calibrated to represent the density of the fluid being moved at any given time. The calibration data can be stored in controller memory as a gain values (voltage bias values) on the

difference in signal frequencies provided by sensing element 40 and accessed by controller logic to make the determination of fluid density at a given time by comparing the signal received from the sensing element 40 with the stored calibration data.

The viscosity and/or density feedback information can be used by the controller 30 to control operation of the piezoelectric device 10. For example, either the fluid viscosity feedback or the fluid density feedback, or both, can be used by controller 30 to vary the output signal SIG delivered to PZT element 20 of the device 10 by controlled source (drive circuit) S.

Those skilled in the art will appreciate that either the viscosity feedback or the density feedback, or both, determined from signals provided by the single PZT sensing element 40 can be used by controller 30 at a given time of operation of the piezoelectric device 10 to this end. Alternately, a pair of PZT sensing elements 40 can be provided on movable member 12 with one providing viscosity feedback and the other providing density feedback to the controller 30.

If viscosity and/or density feedback information is to be provided to the controller 30, the PZT sensing element(s) 40 typically are made of the same PZT material as PZT actuator sensor 20. If the PZT sensing element 40 also is used to drive the movable member 12, it will have a polarity opposite to that of PZT actuator element 20.

In another embodiment of the invention, the PZT sensing element 40 and its lead wire 42 are used to provide to controller 30 feedback information that can be correlated to changes in the temperature of the fluid being moved by the movable member 12. In this embodiment, the PZT sensing element 40 will comprise a PZT material having a different thermal expansion coefficient from that of the PZT actuator element 20. For example, the PZT actuator element 20 can comprise a conventional ceramic PZT material, while the PZT sensing element 40 can comprise a polymer PZT material of the type described above.

As the temperature of the fluid changes (increases or decreases) from ambient, the difference in thermal expansion coefficient between PZT elements 20 and 40 will impart a bend to the movable

